

## Wind power supply chain in China



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### ABSTRACT

Wind power industry has experienced swift development and gradually moved towards maturity in China. However some hiding issues have appeared and threatened its sustainable development. In this paper, we employ the supply chain framework to present a thorough and comprehensive review on China's wind power industry. First we identify key stakeholders along the supply chain and discuss their concerns. Then we summarize the evolution of related policies in both upstream and downstream of the supply chain. The concerns of stakeholders and the existing policies will help understand the progress and challenges of the industry in China. We find that inability of independent technique innovation, unordered and unbalanced pattern of wind farm development, de-motivation of power grid companies, incompatible technical codes of power grid operation, and neglected demand response are among the key issues. Policy recommendations are proposed to address these problems.

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### 1. Introduction

Energy is the material basis for economic and social development. Ever since the Industrial Revolution, fossil energies as coal, oil and gas have been depleted quickly. Meanwhile, ecology system

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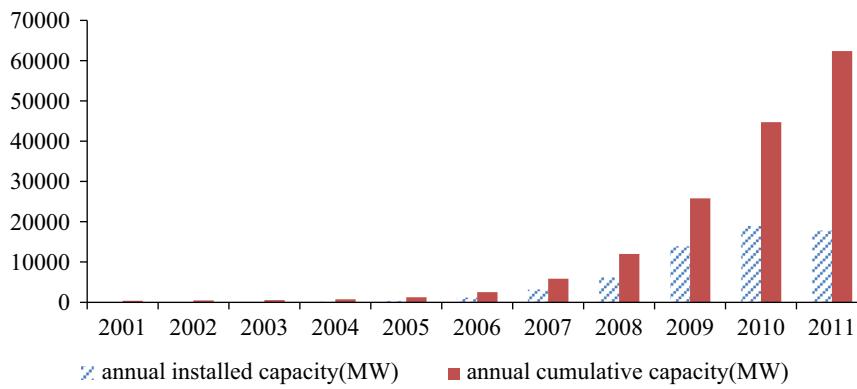


Fig. 1. Annual installed and cumulative wind power capacity in China, 2001–2011.

and environment is deteriorated along with the consumption of fossil energy. Especially, the acceleration of greenhouse gases (GHG) emissions incurred by combustion of fossil fuel has become the top threat of human civilization.

As the biggest developing country as well as the largest GHG emitter in the world, China has been perplexed by issues of too much fossil energy consumption and high environmental cost. Therefore, striving to develop non-fossil energy is an important measure for China to ensure energy security, adjust primary energy structure and respond to climate change. Accordingly, China has pledged a 15% clean energy target and formulated several clean and renewable energy plans [1].

Wind power is among the most promising green energy options due to its superior features of abundance, renewability, wide distribution and zero pollution. In recent years, wind power has been growing rapidly worldwide and plays essential role in the diversification of generation mix.

In the end of 2011, the cumulative installation of wind power in China reached 62.4 GW, accounting for one quarter of world total and holding top position in the world (Fig. 1). In 2011, in China wind power generation could satisfy electricity demand of about 47 million households, representing energy conservation of 22 million tons standard coal equivalents and CO<sub>2</sub> abatement of 70 million tons [2].

However, after several years of rapid development, some issues have gradually appeared and call for thorough and comprehensive review of the industry. The declining growth of wind turbine manufacturers and their deteriorated economic performance, the exacerbated puzzle of grid integration, and the unprecedented high rate of wind power curtailment etc. are among the primary issues. Since 1996 when State Development Planning Commission (SDPC) formulated the *Riding the Wind Program* to initiate wind power market in China, a large body of studies has been conducted. The existing literature can be classified in three streams. The first stream concerns with the status and issues of wind industry in different periods. Ref. [3] pointed out that small market scale is the main reason of sluggish growth of wind power in China during the 1990s. Ref. [4] pointed out that main issues during the early 21st century (2000–2005) are insufficient resource survey, low level of technology and equipment, high cost of power generation and inadequate supporting policy. Their comments were responded by the study in [5]. In [6] it was argued out that power grid is the bottleneck of wind power development. The planning of power grid considering wind integration and standardization of the planning scheme have also been discussed [7]. Ref. [8] identified main obstacles affecting sustainability of the industry, including regulatory factors, grid integration, and technological innovation. Ref. [9] identified four challenges, including uncoordinated development between wind farm and

power grids, lack of technical codes for wind power integration, unclear nature of the grid companies' responsibility for grid connection, and inadequate economic incentives for grid companies. Regarding the low capacity factor of wind power, discordance between wind farm development and grid planning is widely discussed in [10–12]. Ref. [13] identified 19 factors to analyze the strengths, weaknesses, opportunities and threats associated with China's wind power industry.

The second stream concerns with the development pattern of wind power industry. In [14] it was claimed that development of large-scale wind farms in resource enrichment regions should be the priority of policy in China. Ref. [15] proposed a pathway for developing domestic wind power equipment manufacturing. Ref. [16] analyzed the dynamic mechanism of wind supply chain and proposed an operation model. Ref. [17] addressed three relevant issues, namely pricing policies, transmission capacity and the structure of the equipment manufacturing industry and argued that state dominance partly contributed to these issues. Ref. [18] discussed the imbalanced regional distribution of wind farms and its pressure on grid-access. Ref. [19] proposed a performance framework to evaluate China's wind policy and addressed the issue of power tariff reform.

The third stream concerns with policy and function division between government and market [20]. Ref. [21] formulated an improved dynamic diamond model to analyze the competitiveness of China's wind power industry and concluded that it is necessary for the government to strengthen all the elements in the model to make the wind power competitive against coal-fired power. Ref. [22] presented a comprehensive review on policy progress during the 11th Five-Year-Plan (FYP) period and identified three defects in the policy design. Ref. [23] explained how political and institutional factors have determined the relative successes and failures of China's wind power policy over the period 2005–2011. Their finding is that the progress can be attributed to the political motives and institutional arrangements of the Chinese government as well as the institutional changes. But they also argued that improper institutional arrangements are the reasons of two obvious failures of the industry, low proportion of grid-connected capacity and rising trend of wind turbine incidents.

The existing literature has offered valuable inspiration to the formulation of wind power policy in China. However, most of the existing literature is conducted in perspective of macro policy, while the internal structure of wind power industry has seldom been addressed. Though issues relevant to downstream part (wind farm and the grid-access) have been extensively discussed, few efforts have been devoted to the upstream part and the interaction between them.

Ref. [24] proposed to assess renewable energy development and policy design in a supply chain perspective. Conversion efficiency and technology maturity are the key factors to the

performance of renewable supply chain, while economic, social and environmental aspects are the three critical dimensions in understanding the sustainability of renewable energy. The idea proposed in [24] is to check the renewable supply chain from the macro perspective of social economic development. Ref. [25] differentiated the wind power industry chain into supply chain, technology chain and value chain, from a different perspective of industry development. As a matter of fact, current literature on China's wind power industry has clearly indicated that any links in the supply chain have direct impact on the entire industry. In particular, the stakeholders and their concerns have significant impact. The novelty of this review is to pay close attention to the stakeholders in the supply chain and to observe the interactions among stakeholder concerns, policy progress and industry development.

The aim of this paper is to conduct such an analysis, with an emphasis on the stakeholders along the supply chain. The remainder of the paper is as follows. Section 2 will discuss the stakeholders along the supply chain and their concerns. Section 3 will review the related policies along the wind power supply chain. Section 4 will analyze the status and issues of the supply chain. Section 5 will propose policy recommendations and Section 6 concludes.

## 2. Stakeholders and their concerns

The supply chain of wind power is consisted of raw material suppliers, components manufacturers, wind turbine manufacturers, wind farm developers and/or operators, grid operators and the related service suppliers. The process of wind power generation and utilization is shown in Fig. 2 and the mode of wind power supply chain is shown in Fig. 3.

In perspective of supply chain, wind power industry can be divided into two parts, upstream and downstream. The upstream is consisted of raw materials suppliers, components and parts manufacturers, technology servicers, wind turbine manufacturers and wind farm developers. Raw materials suppliers provide raw materials to components manufacturers, then components manufacturers and technology servicers provide components or service to wind turbine manufacturers. Then with the supply of wind turbine from turbine manufacturers and the engineering service provided by engineering contractors, developers conduct investment, siting and infrastructure activity to build wind farms. The downstream is consisted of wind farm operators, grid companies, end-use customers and future customers/distributors equipped with energy-storage facility. Grid companies provide grid-access service to the wind farms and invest in transmission system.

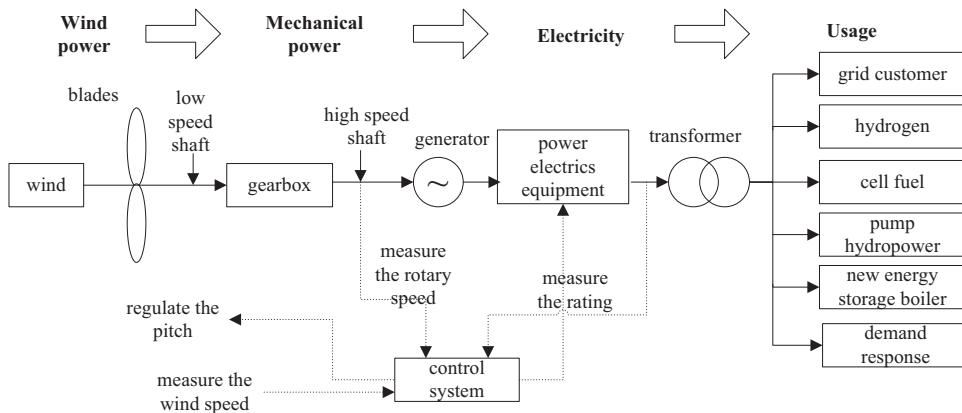


Fig. 2. Wind power generation and utilization.

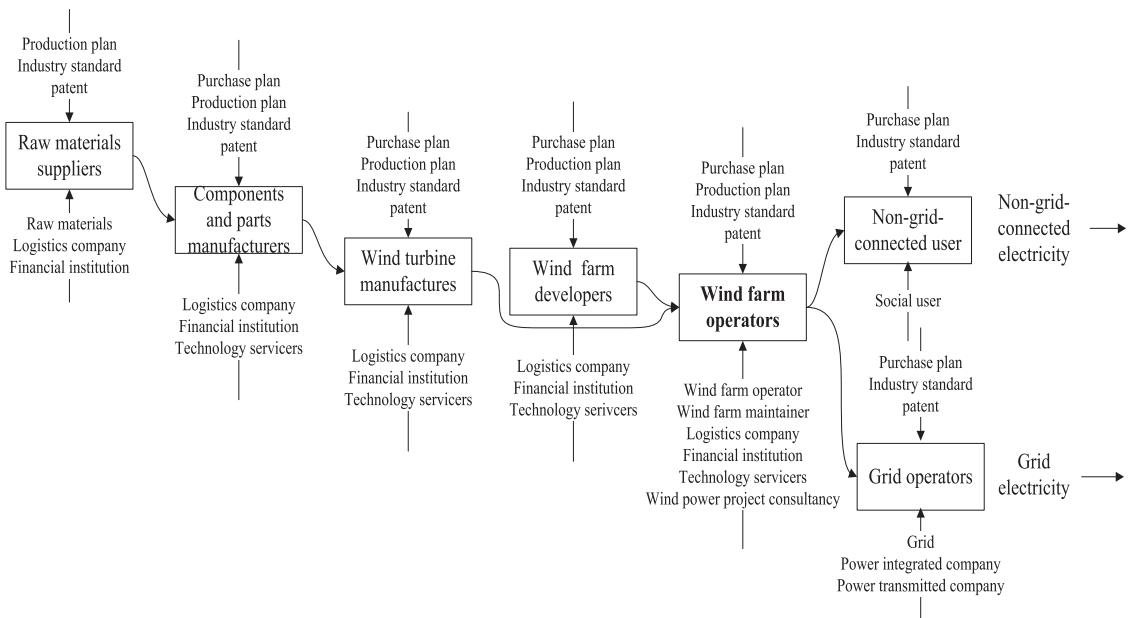


Fig. 3. Wind power supply chain.

The electricity generated from wind power is transmitted to end-use customers via transmission system or stored by energy storage facility such as pumped hydropower.

In this section, we will identify the stakeholders along the wind power supply chain in China. The upstream is the supply chain for wind turbines. There are seven key stakeholders, including central government, R&D institutions, patent owners, components and parts manufacturers, wind

turbine manufacturers, wind farm investors and local governments ([Table 1](#)).

Here central government includes not only State Development and Reform Commission (SDRC), and National Energy Administration (NEA), who are responsible for industry policy, energy planning and price policy, but also Ministry of Finance (MOF) and State Administration of Taxation (SAT), who are responsible for formulation and implementation of fiscal and tax policy.

**Table 1**  
Upstream stakeholders in China's wind power supply chain.

	Stakeholders	Function	Concerns	Related with
Entire supply chain	Government	Industry development Energy planning Renewable energy utilization R&D of new technologies Supply of key technology to manufacturers and wind farm operators Manufacturing and supply of required components and parts for wind turbine Reducing product cost by technology R&D	Fostering new strategic industry Energy security and stable energy supply Environmental and ecological issues Profit sharing from technology service, protection of intellectual property Market share, competitiveness and profit Imitation, R&D and diffusion of key technologies	–
Equipment manufacturing	Technology provider & patent owners			Wind turbine manufacturers
	Components and parts manufacturers			Other components and parts manufacturers
	Wind turbine manufacturers	Assemble wind turbines Engineering service for building wind farms Technology R&D	Market demand, market share and profit Siting of wind farms, profit of the service delivered Production cost, acquirement of new technology	Competitors; wind farm investors; components suppliers Patent owners
Wind farm development	Wind farm investors	Detailed planning of wind farms Investment of wind farms	Wind resource, land price, local government policy, grid access Total investment, expected profit	Local government, wind turbine suppliers, grid companies
	Local governments	Regional wind power resource survey and planning, policy support to wind farm development	Potential contribution to local economy, tax and employment	Central government, grid company, wind farm investors

**Table 2**  
Downstream stakeholders in China's wind power supply chain.

	stakeholders	Function	Concerns	Related with
Entire supply chain	Central government	Overall renewable energy policy Specific pricing, tax and fiscal policy pertinent to wind power	Share of renewable in the energy mix Commercialization of wind power	–
Wind power generation	Patent owners	Providing technology service to wind farms and power grids	Profit sharing from technology service, protection of intellectual property	Wind farms and power grids
	Wind farm operators	Wind power generation	Capacity utilization, dispatch planning	Power grid companies
Power transmission and distribution	Power grid companies	Operation & Maintenance Grid connection of wind farms Dispatch of the power grid	Cost reduction, safe and efficient operation Investment requirement for the transmission system, planning of power grid, profit (difference between retail tariff and wholesale generation tariff) Impact of different power plants to the safe operation, response speed and price of power plants	Patent owners Wind farms, customers, central government Local governments, wind farms
		Application of Smart Grid (and the related technologies)	Benefit of Smart Grid to power grid, role of power grid	Customers, wind farms
Power consumption	Customers	Customers connected to power grid Isolated customers	Stability and price of electricity Price of wind power and distance from the wind farm	Grid companies Wind farms
Entire downstream supply chain	Local governments	Regional power generation planning, policy support to wind farm operation	Stability of regional power supply, wind farm's contribution to local economy	Central government, grid companies, wind farms

Central government plays essential roles in the supply chain in the following ways. First, by formulating related law and planning for renewable energy, strong signal for wind power development is provided. Second, by formulating and implementing supportive industry policy, domestic manufacturing of wind turbine is fostered. Last, by favorable price and tax policy, a strong domestic wind power market is successfully created.

Local governments play facilitative roles in the development of wind power. Because most of wind resources are located in undeveloped areas, local governments have strong incentive to develop wind farms in their administrative districts and compete for investment. For them, the biggest concern is job opportunity and contribution to local revenue. Typically, favorable loan support, tax exemption policy and low cost land etc. are provided to attract investors. But local governments also have their responsibility in the unordered development of wind power. For example, according to regulation, wind power projects with capacity above 50 MW must be checked and approved by SDRC but projects with capacity less than 50 MW will be approved by local governments. To circumvent the strict and lengthy approval procedure by the central government, developers decompose large projects into several 50 MW projects and get them approved by local governments. Naturally, these projects are not listed in the renewable energy planning issued by the central government and as a result, grid connection will be a puzzle. It is also worth noticing that provincial governments have a saying in arranging annual power generation planning. Their preference favors secured power supply, instead of wind power generation [12].

The downstream is the supply chain of wind power and the key links are wind farm (power generation), grid company (wind power integration, transmission & distribution) and customer (utilization). There are eight stakeholders, R&D institutions, patent owners, wind farm operators, grid companies, customers connected to public grids, isolated customers, local governments and central government (Table 2).

Grid companies play vital role in downstream supply chain. According to the provision of *Renewable Energy Law*, grid companies are obliged to fully purchase wind power generation with the necessary grid access conditions. But it doesn't necessarily imply that grid companies have appropriate incentive to provide grid access and transmission service for wind farms. The biggest concern for grid companies is the safe operation of power grids. Wind farms, however, add uncertainty to safe operation. In the operation of power systems, controllable power supply dominates the generation mix. Typically, nuclear power and hydropower serve for base load, coal power for medium load and gas power for peak load. Because of the intermittence character as well as the difficulty of accurate output forecast, it is impossible to put wind power as priority in the dispatching plan. Therefore, proper handling of wind power in dispatch and operation is an urgent requirement on grid technology development. Smart Grid is an imperative solution to it, in that: ultra-high voltage (UHV) system, the key priority of smart grid development in China, can provide better trans-regional transmission service to renewable energy like wind power; smart demand management can provide more

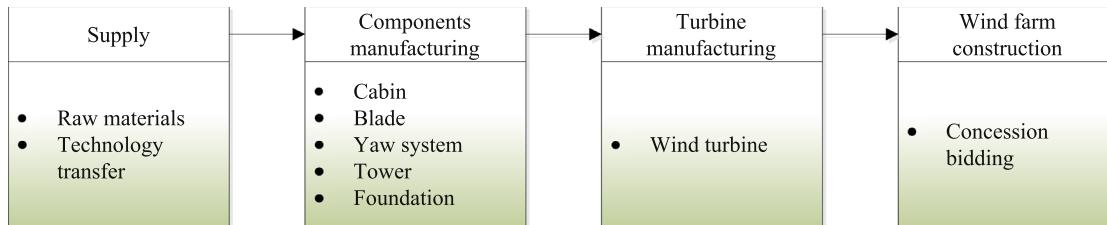
**Table 3**  
Upstream policies for wind power in China.

Time	Policy	Key points and comments
2005	Notice on relevant requirements for the management of wind farm development	<ul style="list-style-type: none"> <li>✓ The key points for the approval of wind farm development are the scale of the wind farm, siting condition and the domestic manufacturing ratio of the wind turbine (no less than 70%)</li> <li>✓ Special attention is attached to domestic manufacturing ratio of the wind turbine in the development of wind farm</li> </ul>
2007	Notice on the relevant import duty policy to implement the decision to revitalize equipment manufacturing industry by the State Council	<ul style="list-style-type: none"> <li>✓ Provide exemption of import tariff and related VAT to domestic manufacturers for the import of key components and material of wind turbine</li> <li>✓ Import substitution is taken as the priority to foster domestic wind turbine manufacturing industry</li> </ul>
2008	Interim measure on the special fund for promoting domestic wind turbine manufacturing industry	<ul style="list-style-type: none"> <li>✓ Provide subsidy of 600 RMB/kW for the first 50 units of MW scale wind turbine for qualified manufacturers. The subsidy will equally be shared between wind turbine manufacturers and key components (especially converter and bearing) manufacturers. The subsidy can only be used for the R&amp;D of new wind turbine</li> <li>✓ Public money is used to provide incentive for product innovation.</li> </ul>
2009	Decision on restraining over capacity and guiding the healthy development of some industries	<ul style="list-style-type: none"> <li>✓ Strictly control the blind expansion of wind turbine manufacturing. Forbid the provisions in the bidding specification that the wind turbine must be manufactured locally. Establish and perfect the standard of wind power equipments and the related test and certification system. Enhance the research on the technology roadmap of wind power and technology R&amp;D of offshore wind power. Perfect the quality control system for the wind power manufacturing</li> <li>✓ Guide the healthy development of domestic wind turbine manufacturing after rapid market expansion</li> </ul>
2010	Draft on the admittance standard for wind power manufacturing industry	<ul style="list-style-type: none"> <li>✓ Formulate six conditions for establishing wind turbine manufacturing enterprise: no less than 30% of self-fund in the whole investment; equipped with all the facility to produce 1 GW/year at no less than 2.5-MW unit for the new investment, installation performance of no less than 0.5 GW for the expansion investment; five years of business experience in large-scale mechanical and electronic industry for the new enterprise; transportation convenience; full supply chain matched with wind turbine manufacturers</li> <li>✓ Increase the market concentration and improve the competitiveness of domestic manufacturers</li> </ul>
2011	Notice on strengthening safety management of wind farm and containing accidents of wind farm operation	<ul style="list-style-type: none"> <li>✓ Formulate retrofitting plan to the wind turbine units that cannot satisfy the condition of low voltage ride through (LVRT)</li> <li>✓ The government begins to pay attention to the impact on power grid when the scale of grid accessed wind power accounts for significant portion of total generation capacity in some regional power grids</li> </ul>

**Table 4**

Downstream policies for wind power in China.

Time	Policy	Key points and comments
2005	Renewable Energy Law	<ul style="list-style-type: none"> <li>✓ Require that grid companies fully purchase the renewable generation and provide grid-access service to renewable generators. The surcharge of purchased price of the grid company should be allocated by all customers in retail tariff</li> <li>✓ Provide legislative base for renewable energy development and strong incentive for wind power</li> </ul>
2006	Trial measures on the generation price and cost allocation of renewable energy	<ul style="list-style-type: none"> <li>✓ Implement government referential price for electricity generated from wind power and the price will be determined by department in charge by tender offering. An additional fee will be collected from electricity customers to solve the issue of high price of renewable power generation</li> <li>✓ Provide the practical way to implement provisions of the Renewable Energy Law</li> </ul>
2007	Supervision measures to power grid companies on the full purchase of renewable power generation	<ul style="list-style-type: none"> <li>✓ Grid companies are liable to fully purchase the grid-accessed renewable power generation in its coverage area and renewable generators should provide the necessary aid. Grid companies are responsible for disclosure of the related information</li> <li>✓ Provide practical measure for grid-access of wind power.</li> </ul>
2008	Notice on the integrated utilization of resource and VAT policy of other products	<ul style="list-style-type: none"> <li>✓ Wind power operators can enjoy the policy of 50% exemption of VAT</li> <li>✓ Provide fiscal support to wind farm</li> </ul>
2008	Notice on the preferential income tax catalog for enterprises in the field of public infrastructure	<ul style="list-style-type: none"> <li>✓ Allow wind farm operators to deduct the input VAT of the newly-installed turbine at the current VAT rate. The wind farm operators are eligible for full exemption of income tax for the first three years of regular business operation and half exemption for the second three years</li> <li>✓ Provide fiscal support to wind farm</li> </ul>
2009	Notice on policy to perfect wind power generation price	<ul style="list-style-type: none"> <li>✓ Divide the whole nation into four resource areas and set the benchmark price of 0.51, 0.54, 0.58 and 0.61 RMB/kW h. Offshore wind price will range between 0.62 and 0.97 RMB/kW h and is determined by the combination of bidding and approval</li> <li>✓ Simplify the price mechanism of onshore wind power and set up the pricing mechanism for offshore wind power</li> </ul>
2011	Notice on the approval of first batch of wind power projects during the 12th FYP period	<ul style="list-style-type: none"> <li>✓ Approve wind power projects of 28.83 GW during the 12th FYP period and provide a detailed project list. The unlisted projects cannot be approved and accessed to power grid and cannot enjoy the renewable subsidy</li> <li>✓ Formulate planning of wind power during the 12th FYP period</li> </ul>

**Fig. 4.** Upstream wind power supply chain.

flexibility in the demand side and facilitate the utilization of intermittent wind power; and smart dispatch, based on the big data platform, can better match the profile of demand and output at shorter interval and promote the penetration of wind power. Another concern of grid companies is the cost incurred by wind power. Extra transmission facility and extra reserve capacity for wind power bring forth extra cost to grid companies. But there is no specific provision in the *Renewable Energy Law* on this issue.

Typically power customers care about stability and reasonable price of power supply, but rarely care about where it is from. But in some developed countries like USA, mechanism as green certificate has successfully involved customers in and ignites their enthusiasm to green power. In many European countries like German and Netherlands, a private investor can erect a wind turbine and arrange power supply directly with final customers and grid companies are obliged to provide transmission service. But in China, current monopoly supply of grid companies has essentially eliminated these possibilities.

### 3. Policy progress

In this section we will discuss the relevant policies in both upstream and downstream. To save space, we will simplify the specific

policies in tables and only address the key points (Tables 3 and 4). It is worthwhile noticing that the focus of upstream policies is to encourage the domestic manufacturing of wind turbine while that of downstream is on the investment of large-scale wind farms by providing strong price signal. The adjustment in the exemption of import duty from wind turbines to main components, the subsidy to turbine manufactures on new MW-size turbine models clearly indicate the government's priority in promoting domestic production. In the downstream part, the legal requirement of full purchase of wind power generation, the regionalized Feed-in-tariff (FIT) policy, and ambitious planning show the government's determination to develop wind power at large-scale.

### 4. Status and issues

Overall, there are lots of imbalances in the upstream and downstream of the supply chain. In the upstream the capacity of supply takes the lead but the R&D capability is weak. In the downstream the speed of wind farm development is fastest in the world but the capacity of wind power integration and final usage is poor. In one word, the mismatching along the supply chain poses serious threat to the commercialization of wind power in China.

In the upstream, manufacturing of MW-unit wind turbine is still in the initial stage. By means of joint R&D with foreign manufacturers or gaining license from them, domestic manufacturers are capable of producing wind turbine at MW scale. But technology digestion is weak and mass production is still problematic. Meanwhile, the capacity of domestic manufacturers on manufacturing of key components, especially the blade, gear box and main bearing is weak and cannot meet the requirement of domestic market. In the downstream, development of wind farms is rapid. Investors, especially the state-owned (SOE) national generators are keen on wind power development and bring strong demand on wind turbines. But final usage of wind power generation is restrained by grid connection and other issues.

#### 4.1. Upstream supply chain

The upstream part of wind supply chain can be divided in components and turbine manufacturing (Fig. 4).

#### 4.1.1. Wind turbine manufacturers

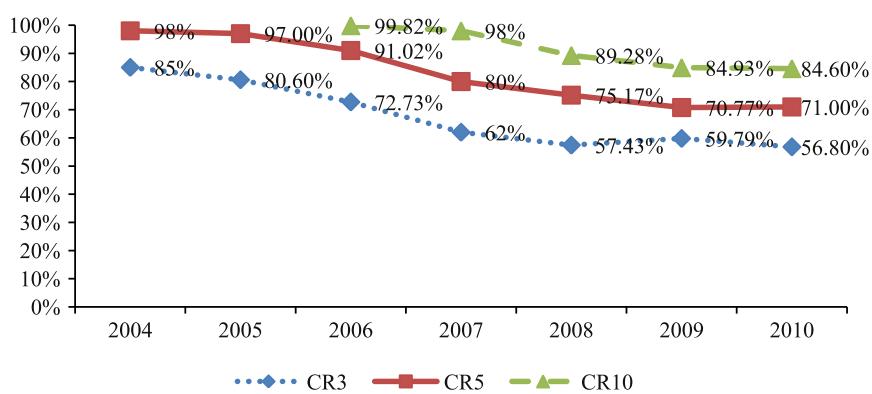
**4.1.1.1. Status.** In 2011, there were 29 wind turbine suppliers in China. The number was 38 in 2010 and 43 in 2009. It is worth noting that the meaning of supplier differs with manufacturer here and means company who sells wind turbine. There are about 70 registered manufacturers in China though not all of them contribute to domestic supply every year.

Wind turbine manufacturing is an industry with obvious economy of scale. Only those manufacturers with solid capital base can attract and aggregate talents and decrease production cost by technology innovation. So it is not surprising that first movers possess scale and technology advantages and are always the successful bidders in wind power projects. Therefore, it is an industry with high market concentration. In newly increased installation of 2011, five top suppliers were Goldwind 3600 MW (20.4%), Sinovel 2939 MW (16.7%), United Power 2847 MW (16.1%), Mingyang 1177.5 MW (6.7%) and DTC 946 MW (5.4%). While in the end of 2011, top five suppliers of cumulative installation were Sinovel 12,977 MW (20.8%), Goldwind 12,678.9 MW (20.3%), DTC 6898 MW (11.1%), United Power 5282 MW (8.5%) and Vestas 3565.5 MW (5.7%) (Table 5) [26]. Top five hold more

**Table 5**

Top 20 wind turbine suppliers in China in 2011.

Unit: MW	Newly increased supply in 2010	Cumulative supply in 2010	Newly increased supply in 2011	Cumulative supply in 2011
Goldwind	3,735	9,078.85	3,600	12,678.9
Sinovel	4,386	10,038	2,939	12,977
United Power	1,643	2,435	2,847	5,282
Mingyang	1,050	1,945.5	1,177.5	3,123
DTC	2,623.5	5,952	946	6,898
XEMC	507	1,089	712.5	1,801.5
Shanghai Electric	597.85	1,073.35	708.1	1,781.5
Vestas	892.1	2,903.6	661.9	3,565.5
CCWE	486	682.5	625.5	1,308
CSR Zhuzhou	334.95	465.3	451.2	916.5
GE	210	1,167	408.5	1,575.5
Haizhuang	383.15	479.25	396	875.3
Windey	129	723	375	1,098
Gamesa	595.55	2,424.3	361.6	2,785.9
Envision Energy	250.5	400.5	348	748.5
Yinxing Energy	154	252	221	473
SANY	106	143.5	179.5	323
XJ Wind power	22	26	166	192
HY	161.64	295.08	151	446.1
Suzlon	199.85	805.1	96.2	901.3
Others	460.9	2,354.47	259.3	2,613.7
Total	18,928	44,733.3	17,630.8	62,364.2



**Fig. 5.** Market concentration of wind turbine manufacturing in China.

than 60% of the total market share in China (refer to the Appendix for the company names appeared in the text).

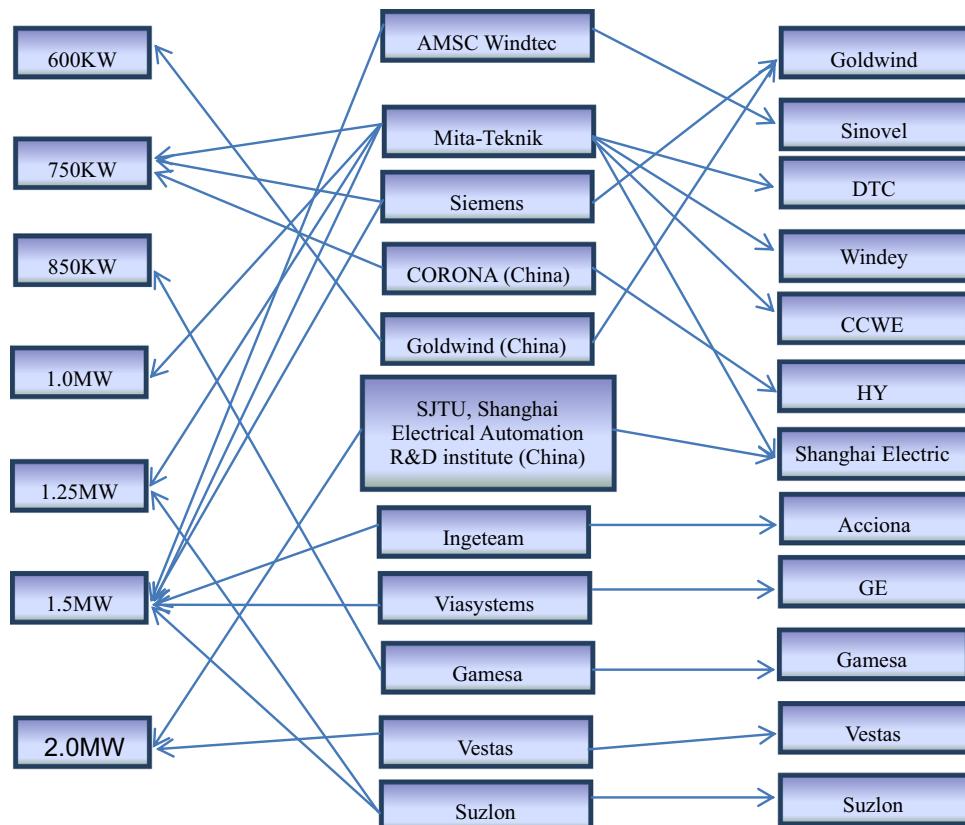
Due to rapid market expansion, more companies are encouraged by favorable policy and enter into wind turbine manufacturing. The market concentration, at the same time, declines slightly year by year in China (Fig. 5) [27].

**4.1.1.2. Issues.** The first is lack of national technology standard. Though manufacturers preliminarily grasp the technology at MW scale, the generality and expansibility of the technology remains problematic due to lack of national standard.

The second is overcapacity. In 2007 there were only about 30 wind turbine manufacturers in China. However in just one year

**Table 6**  
Trend of wind power technology development.

Field	Development trend
Wind turbine	<ul style="list-style-type: none"> <li>✓ 1.5 MW and above unit is the mainstream model in the market</li> <li>✓ High-power offshore wind turbine is leading edge of the market</li> <li>✓ 10 MW offshore wind turbine has been successfully developed</li> </ul>
variable-speed operation	<ul style="list-style-type: none"> <li>✓ Possess properties of high power generation efficiency, flexibility to variable wind speed and low production cost</li> <li>✓ German company Enercon takes the leading position</li> </ul>
generator	<ul style="list-style-type: none"> <li>✓ The mainstream technology currently is dual-fed, pitch and variable speed generator</li> <li>✓ Stalled, variable-pitch and variable-speed generator is not the mainstream technology, but it is mature and has stable performance and much O&amp;M experience</li> <li>✓ Direct-driven, permanent magnet, variable-pitch and variable-speed generator is the future direction</li> </ul>
Gearbox	<ul style="list-style-type: none"> <li>✓ Direct-driven without gear box can efficiently improve the system efficiency and operation reliability</li> </ul>
Blade	<ul style="list-style-type: none"> <li>✓ Development from fixed to variable pitch is the direction</li> <li>✓ Detachable cluster is the direction adapted to the trend of enlarged blade</li> <li>✓ Raw material of the blade will develop from current resin reinforced by glass fiber to high intensity and light weight carbon fiber</li> </ul>
Electronic control device	<ul style="list-style-type: none"> <li>✓ Application of advanced control theory</li> <li>✓ Non-impact speedy grid connection</li> <li>✓ Remote monitor and control</li> <li>✓ Independent blade control</li> <li>✓ Isolated wind turbine or weak grid operation</li> <li>✓ Hybrid control of wind power and PV</li> </ul>



**Fig. 6.** Mating among electronic control and wind turbine companies.

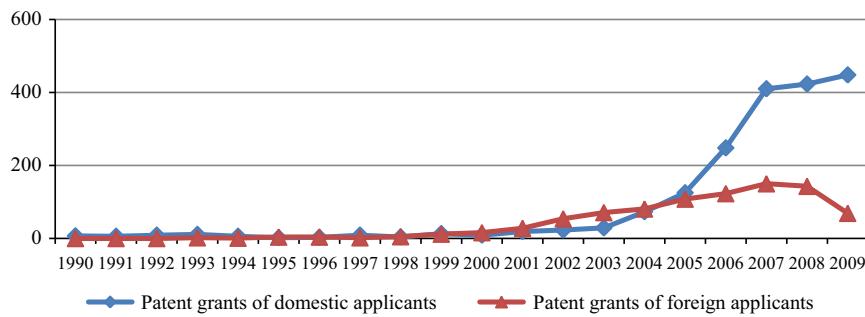


Fig. 7. Patent application in wind turbine industry.

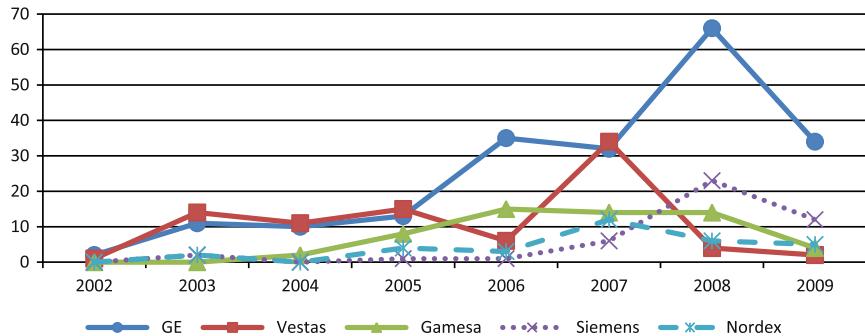


Fig. 8. Patent application of foreign applicants in China.

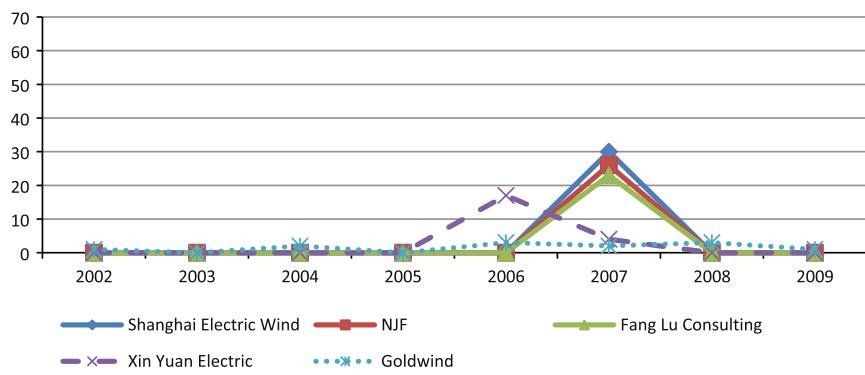


Fig. 9. Patent application of domestic applicants in China.

more than 40 companies entered into the industry after Goldwind, the leading domestic manufacturer went public in the end of 2007. This kind of blind entrance results in overcapacity. Now top 10 suppliers hold about 90% of the market share while the rest of 90 manufacturers compete for the remaining 10% market share and most of them can never gain their order.

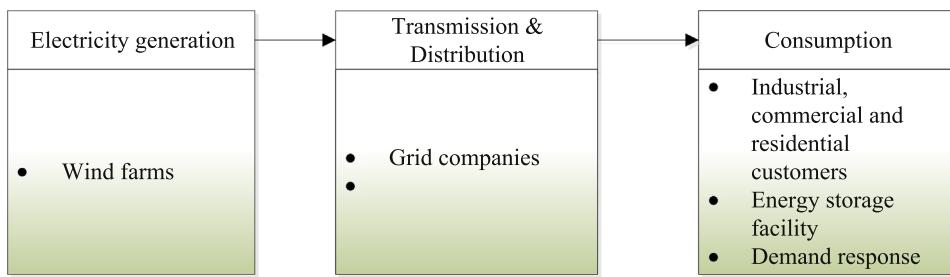
The third is quality issue. Most of the wind turbine technology is imported and has not gone through scientific appraisal and re-innovation to adapt to local conditions. Additionally, because supply falls short of demand for several years, many wind turbines are put into volume production even without trial operation. When these turbines are connected to the power grids, they will pose potential quality issue and safety hazard.

#### 4.1.2. Components and parts manufacturers

**4.1.2.1. Status.** The components and parts manufacturing in China is growing quickly and the production and supply system is improved gradually. Now in China a system capable of manufacturing key components as blade, gear box, generator, variable yaw system,

wheel hub and tower is established. However, domestic components manufacturing can hardly keep up with the trend of global technology development. Table 6 provides a brief of the trend and after that we will analyze the status in China.

Since 2008, supply of components and parts can meet the market demand in China. Some of them are supplied by domestic manufacturer while others are supplied by factories established by foreign companies. Among them, more than twenty companies manufacture blades or conduct R&D and trial production activities for blades. The production capacity for blade in China is growing quickly and an integrated supporting system is formed. Representative companies like HT, Zhongfu Lianzhong, and SHFRP etc., have realized volume production of high-power wind turbine blades by means of technology import or joint-design. For gear box, more companies have entered in but production capacity grows very slowly. Most of the wind turbine gear box manufacturers in China have years of experience in the manufacturing of large-scale gear boxes, for example NGC, CN GPOWER, and ADVANCE. The first two companies account for 80–90% of domestic market share. For generator, the industrial foundation is sound and there are many companies operating in China. The

**Fig. 10.** Downstream supply chain of wind power.

**Table 7**  
Top 10 wind farm developers in China in 2011.

Developers	Annual newly added capacity (MW)	Market share (%)
China Guodian Group	3,860.5	21.9
China Datang Group	2,235.1	12.7
China Huaneng Group	2,229.0	12.6
China Huadian Group	1,104.5	6.3
Guohua Group	1,094.5	6.2
China Power Investment Group	866.3	4.9
China Resource Group	796.1	4.5
China Guangdong Nuclear Power	527.0	3.0
Beijing Energy Investment Holding Co. Ltd	372.0	2.1
China Suntien Green Energy	343.6	1.9
Others	4,202.9	23.9
Total	17,630.9	100.0

suppliers that provide generators for large-scale wind turbine are YONGJI, LEC, XEMC, TMT, SEC, Tianyuan Electric, DEC Dongfeng and Nanyang Electric etc.

It is worth noting that previously main-shaft bearing, gear box bearing and converter were completely dependent on import but now domestic suppliers can realize volume production. Therefore, the restrictions on these key components are mitigated and manufacturing cost of wind turbine as a whole is reduced to some extent. But electronic control system is the weakest link and fully depends on import. The main foreign suppliers are Mita-Teknik and AMSC's Windtec. Several Chinese companies are still in the R&D and test production stage, for example, CORONA, SUNGROW, XJ Wind Power, NARI, Tianyuan Electric, etc. Among them, CORONA successfully developed a prototype of 1.5 MW double-fed, variable-speed and constant-frequency control system in 2006, which is the first control system with proprietary intellectual property rights and in practical operation. Fig. 7 provides a diagram for the mating among electronic control and turbine companies. It is clear that domestic manufacturers can only provide electronic control systems for 600 kW and 750 kW turbines, but MW-unit turbines and above are dominated by foreign companies or their subsidiaries in China [27] Fig. 6.

Analysis of patent application can provide interesting evidence. Fig. 7 compares the patents application for wind turbine between domestic and foreign applicants. It is evident that the quantity of applications has grown rapidly since 2001 and foreign application contributed most of the growth before 2005, while after 2005 domestic application began to exceed foreign application [26]. But it doesn't necessarily imply that innovation capability of Chinese wind turbine manufacturers catches up with their foreign counterparts since 2005. Figs. 8 and 9 present the patent application from the strongest domestic and foreign applicants [28]. It is clear that patent applications from foreign applicants have absolute

**Table 8**  
Cumulative grid-connected wind capacity in China in 2011.

Developers	Cumulative grid-connected capacity(MW)
China Guodian Group	9,812.9
China Huaneng Group	6,581.0
China Datang Group	5,743.0
Guohua Group	2,353.0
China Huadian Group	2,837.1
China Guangdong Nuclear Power	2,200.6
China Power Investment Group	2,124.5
China Resource Group	1,382.8
China Three Gorges Group	1,340.3
Others	13,460.4
Total	47,835.6

advantage in not only the quantity requested, but also continuity of development. While for domestic applicants, it is evident that their applications are active only in discrete year and lack continuity. The type of applicants is also revealing. For Chinese applicants, individual persons account for 50% of total applications, universities and research institutes account for 20% while companies account for the rest of 30%, which is clear evidence that the innovation capability of Chinese companies is weak. But for foreign applicants, companies account for 81.6% of the total applications, which is strong evidence that foreign companies are the driving force of innovation in wind turbine manufacturing.

**4.1.2.2. Issues.** First, some key components are still the constraints for the release of domestic manufacturing capacity. Before 2006 the mainstream model of wind turbine in China was low-power set (600 kW or 750 kW) and it is relatively easy to attain breakthrough in the manufacturing of key components. But as the unit size of Chinese wind turbines has increased remarkably (from kW-level to MW-level), the difficulty to master the know-how of key components increases.

Second, supply of some components, for instance blade and tower, is overcapacity due to low technical threshold. It is estimated that top 10 manufacturers can fully meet domestic market demand for blades but there are more than 50 blade manufacturers in China.

Third, most of the components manufacturers simply rely on lower price to expand their market share, which results in vicious competition and harms the whole industry. Finally poor standardization is still a deterrent to the healthy development of the industry.

#### 4.2. Downstream supply chain

Downstream part of wind power supply chain concerns with wind farm, wind power generation and final utilization (Fig. 10). It is worth noticing that development pattern in China differs greatly

**Table 9**

Statistical data of wind power curtailment in China, 2010.

Region	Curtailment rate (%)	Wind farms surveyed
East Inner Mongolia	22.99	98
Jilin	20.49	44
West Inner Mongolia	17.51	129
Gansu	16.99	39
Heilongjiang	14.49	59
Liaoning	10.34	74
Xinjiang	3.21	32
Hebei	3.09	74
Shandong	1.46	57
Ningxia	0.64	33
Total	11.12	639

from that in Europe and the USA. Wind farms in Europe and the USA distribute widely and power generated is mainly balanced with local demand. But in China, the scale of wind farms grows even bigger and most of electricity generated from wind power is consumed across regions.

#### 4.2.1. Wind farms

Large SOE generation companies have always held the lead in wind farm development in China. Now there are more than 60 companies participating in wind power investment and development. Leaving aside several SOE generation companies, the rest of them are much smaller. Generally speaking, wind farm developers in China can be divided into types as follows: large-scale SOEs affiliated to central government, SOEs affiliated to local governments, private companies, foreign-owned companies and wind turbine manufacturers involving in power generation.

In 2011, the top 10 wind farm developers installed capacity of 13.43 GW, accounting for 76.2% of annual newly-added installation. Table 7 provides detail information about the top 10 wind farm developers in 2011.

According to field statistics, in the end of 2011, SOE wind developers had 37.98 GW of wind power capacity, accounting for 79.4% of the total grid-connected capacity (47.83 GW); private developers had 2.18 GW, accounting for 4.6%; foreign-owned developers had 600 MW, accounting for 1.31%; the rest of 14.7% (7.05 GW) was hold by joint venture companies (Table 8). Among which, the top five SOE generation companies had 27.1 GW, accounting for 57% of cumulative grid-connected capacity. China Guodian Group ranked top with cumulative capacity of 9.81 GW, China Huaneng Group and Datang Group ranked second and third with 6.58 GW and 5.74 GW, respectively.

##### 4.2.1.1. Operation of wind farm.

In this subsection, we will discuss two important issues relevant to the operation of wind farm in China, capacity utilization and CDM revenue.

The curtailment of wind power is serious in some regions and capacity utilization factor is decreasing. The issue of grid access is gradually becoming the greatest challenge of wind power development in China. Wind resources are mainly distributed in the Three-North regions, namely northeast, northwest and northern China. However, the demand is mainly located in eastern coastal regions. Generally speaking, the distribution of wind resources and power demand is not matched geographically. In the past few years, the development of wind power has been highly concentrated in the three-north regions. However, because of asynchrony between wind power and power grids development, lack of adjustable backup capacity, and lack of coordination in trans-province electric power trade, the bottleneck of grid-access becomes acute. As a result, curtailment of wind power increases, especially in the three-north regions.

Issue of curtailment became serious in 2010 when total installation reached 44.73 GW but 31% of it could not be connected to the power grids. In March of 2011, State Electricity Regulation Commission issued its regulation report on wind and PV power generation [29]. In the report, detailed statistical data for wind power curtailment is provided (Table 9). In 2010, Inner Mongolia, Jilin, Gansu and Heilongjiang were among the most serious regions of curtailment, with curtailment ranging between 15% and 20%.

In 2012, National Energy Administration issued a report on annual utilization hours of wind farms in 2011 [30]. According to the report, the national average in State Grid regions was 1928 h while it was 1801 h in China Southern Grid regions. The lowest region was Jilin province with just 1610 h. If taking 2000 h as the break-even point, in 2011 wind farms in only 14 provinces could earn positive profit and almost half of them were losing money. It is estimated that in 2011 direct economic loss caused by wind power curtailment amounted to 5 billion RMB. A 2013 report by NEA indicated that in 2012 the curtailment was even worsened [31].

With the implementation of clean development mechanism (CDM) created by Kyoto Protocol, many wind power projects have successfully gained support from CDM. In the end of March 2010, there were 181 wind projects successfully registered in UN, totaling 946 MW and approximating GHG abatement of 178 million tons CO<sub>2</sub> equivalents. Renewable energy projects can sell CERs by means of trade in the carbon market and acquire carbon revenues. According to World Wildlife Fund, CERs revenues roughly account for 10% of total projects investment and can increase internal rate of return (IRR) of wind power projects from 6.81% to 9% [32]. Therefore, CERs can remarkably enhance the revenues of wind power project and increase its attractiveness. As a matter of fact, in China wind power accounted for 65% of the registered CDM projects. According to current trade price of CO<sub>2</sub>, CDM subsidy can bring forth 0.05–0.07 RMB per kW h electricity generation. However, due to the elevated threshold of getting CDM registered, recently the percent of denied projects has increased substantially. And more importantly, with expiration of the first phase of Kyoto Protocol in the end of 2012, the sudden slump of CERs price will bring great uncertainty to wind power projects in China.

##### 4.2.1.2. Issues.

According to our study, key issues on wind farm development in China can be summarized as follows.

Lack of scientific appraisal in siting: First, current version of wind resource map in China is not elaborate enough to guiding siting work. Second, some local governments hasten in wind farms projects, even without professional resource survey and appraisal. As a result, some wind farms cannot justify the initial investment due to poor capacity factor.

Restriction of grid connection: Because of the long distance of power transmission, extensive engineering work involved and the resulted long construction time, and more importantly, the imbalance between planning of wind farms and power grids, some wind farms cannot be connected to power grids and generate electricity.

Unreasonable pricing mechanism for wholesale wind power generation: when the prices of wind power were determined case by case by means of franchise bidding, policy of “successful bidders with the lowest bidding price” has attacked the enthusiasm of investors greatly because it created vicious competition among them. In 2009 China introduced fixed price for wind power and set four types of wind power benchmark prices across the country. The fixed pricing mechanism ensured investor profits and thus promoted wind power development in the first few years [33]. The benchmark price is consisted of two components. The first is benchmark price of newly constructed de-sulfurized coal-fired power generation and the second is subsidy set by the central government and paid by means of surcharge in the retail tariff.

However large-scale integration faces challenges under such fixed pricing. The major reason is that the imbalance in the regional distribution of wind resources and power load centers creates the need for cross-provincial trade, but fixed pricing has blocked its implementation. A case study by [12] revealed that different fixed prices for different areas make it difficult and even impossible to trade wind power across provinces (or provincial entities).

#### 4.2.2. Power grid companies

In light of the developmental pattern in China, grid companies play essential role in wind power development. However, grid companies have complex attitude and their roles in developing wind power are complicated. Large-scale integration of wind power has imposed great challenges to safe operation of power grids in many ways.

The intermittence character of wind power increases the difficulty of peak regulation. According to field statistics, the probability of anti-peak regulation for wind power in Northeast, West Inner Mongolia and Jilin grids is 60%, 57% and 56% respectively. Because of wind power, in Jilin power grid the period of enlarged peak valley load amount to 201 days in a year. Without sufficient generation capacity for peak regulation, curtailment of wind power in Jilin and Inner Mongolia is the unavoidable choice.

Wind power also brings difficulty of voltage control for power grids. With the large-scale integration of wind farms, power grids become hard to be controlled. According to field statistics, the 110 kV transmission lines must be operated at more than 113 kV voltages and the bus-bar voltage of 220 kV lines must be operated at more than 238 voltages to support regular system voltage in Xinjiang power grid. In that way, it is very difficult to adjust the operation voltage. Besides, the operation of wind farms excessively relies on reactive compensation and it limits the flexibility of grid operation. For instance, when reactive compensation equipment in Tara region of West Inner Mongolia was outage, the peak voltage of the 220-kV system increased to 257 kV.

The poor anti-disturbance capability of wind turbines influences safe operation of power grids. When there is small perturbation in the power systems, outage of wind turbines will bring second impact on power grid and result in amplification of the faults. Wind power will also increase the frequency of shocks to the power grids.

What is more important, additional investment for transmission enlarges the financial burden of the grid companies and pushes up the operation cost. On the opposite they can't gain extra revenue according to current pricing mechanisms. In a word, wind power imposes great safety and operation difficulties to grid companies but brings no extra income for them.

### 5. Policy recommendations

#### 5.1. Promoting domestic wind turbines manufacturing by stronger independent innovation

Domestic wind turbines manufacturing can directly reduce the capital cost of wind farms and promote the commercialization of wind power. It can also break the import dependence of key components and core technologies on foreign supply and enhance the competitiveness of domestic wind turbine manufacturers. Currently industry policy pertinent to wind turbine manufacturing is mainly concerned with cultivation of domestic manufacturing capability and expansion of domestic market. In the future, the focus should be switched to independent innovation capability. Therefore scientific industry planning and technology development pathways should be formulated. A technology innovation system with companies playing leading roles, guided by market demand and co-funded by public and private money should be established. The following policies are suggested to the government:

- Provide fiscal support and preferential tax to those manufacturers conducting independent innovation and enhance the protection on intellectual property rights.
- Formulate and enforce industrial standard for wind turbines and improve the generality of wind turbine equipments.
- Strengthen monitor on market concentration and implement necessary antitrust measures to curb it.
- Enhance quality control of components production process and construct qualified supply system for key components.

#### 5.2. Establishing specialized wind resource survey institution and providing elaborate wind resource mapping

At present, there is no national wind resource survey institution in China. Accordingly there is no professional service for the approval of wind farm projects. With the operation of such an institution, thorough survey of wind resource can be conducted and elaborate wind resource mapping can be provided to help with project approval.

#### 5.3. Developing wind power in both concentrated and distributed ways and encouraging private investment

To ease the difficulty of grid connection, it is comprehensible that China began with concentrated development. However, basically wind power is distributed, so concentrated way won't work in the long run. Once distributed development is initiated, the next step is to lift the control on investors. The government should establish a level playground for all prospective investors.

#### 5.4. Speeding up the construction of power grids

To resolve the issue of grid connection, following suggestions are proposed:

- The government can set up performance index measuring grid connection for grid companies.
- The government can provide subsidy to recover the additional cost of grid companies for integrating wind power.
- Speed up the construction of Smart Grids. Ultra-high voltage transmissions system can promote grid access of large-scale wind farms, while smart distribution network can promote the development of distributed wind power generation.

#### 5.5. Optimizing the dispatch of power system

In China, under the current conditions, without technical retrofitting and reform of dispatching code, it is difficult for coal and CHP plants to conduct deep load regulation. The following ways can be used to solve the issue.

- Add more pumped storage hydropower or gas plants to improve the peak load regulation capability of the power grids.
- Provide incentive for those coal plants which provide more peak load regulation service.
- Incorporate load regulation into the performance indexes of coal power plants and disclose the information in the annual SERC regulation report.

#### 5.6. Attaching importance to energy storage and demand-side response

The massive development of wind power must be supported by large-scale energy storage. The introduction of energy storage facility

**Table A1**

List of wind turbine, components and service companies in China.

Company	Abbreviation
Goldwind Science & Technology Co., Ltd.	Goldwind
Sinovel Wind Group Co., Ltd.	Sinovel
Guodian United Power Technology Co., Ltd.	United Power
China Ming Yang Wind Power Group Ltd.	Mingyang
Dong Fang Turbine Co., Ltd.	DTC
XEMC Wind power Co., Ltd.	XEMC
Shanghai Electric Group Co., Ltd.	Shanghai Electric
China Creative Wind Energy Co., Ltd.	CCWE
CSR Zhuzhou Electric Locomotive Research Institute Co., Ltd.	CSR Zhuzhou
CSIC (Chongqing) Haizhuang Windpower Equipment Co., Ltd.	Haizhuang
Zhejiang Windey Co., Ltd.	Windey
Envision Energy Ltd.	Envision Energy
Ningxia Yinxing Energy Co., Ltd.	Yinxing Energy
SANY Group	SANY
CET XJ Windpower technology Company	XJ Wind Power
Huayi Electric Apparatus Group	HY
Zhonghang Hui Teng Windpower Equipment Co., Ltd.	HT
Lianyungang Zhongfu Lianzhong Composites Group Co., Ltd.	Zhongfu Lianzhong
Shanghai FRP Research Institute Co., Ltd.	SHFRP
Nanjing High-Speed & Accurate Gear Group Co., Ltd.	NGC
CN GPOWER Gearbox Co., Ltd.	CN GPOWER
Hangzhou Advance Gearbox Group Co., Ltd.	ADVANCE
Yongji Xinshisi Electric Equipment Co., Ltd.	YONGJI
Lanzhou Electric Corporation	LEC
Xiangtan Electric Manufacturing Group	XEM
Zhuzhou Times New Material Technology Co., LTD.	TMT
Shanghai Electric Group Shanghai Electric Motor Co., Ltd.	SEC
Dalian Tianyuan Electrical Machinery Co., Ltd.	Tianyuan Electric
DEC Dongfang Electric Machinery Co., Ltd.	DEC Dongfang
Shanghai Nanyang Electrical Machine Complex Co., LTD.	Nanyang Electric
CORONA Science & Technology Co., Ltd.	CORONA
Sungrow Power Supply Co., Ltd.	SUNGROW
NARI Group Corporation	NARI
China Tianyuan New Energy Technology Co., Ltd.	TIANYUAN
Shanghai Jiao Tong University	SJTU
Shanghai Electrical Automation R&D institute Ltd Inc	Shanghai Electrical Automation R&D institute
Shanghai Huiya Electronic Co., Ltd.	HUIYA
Shanghai Electric Wind Co., Ltd.	Shanghai Wind
Nan Ji Feng Electric Equipment Co., Ltd.	NJF
Fang Lu consulting co., Ltd.	Fang Lu consulting
Tianjin Xin Yuan electric technology co., Ltd.	Xin Yuan electric
CASC-Acciona (joint venture by China Aerospace Corporation, Acciona and Inceisa)	Acciona

can effectively reduce the shock of wind power to power systems. In northeast or northwest China where wind resources are abundant and heating load during heating season is high, combination of wind farms with regional heating can bring forth huge benefit. Electric heating or energy storage boiler can be viable ways for its implementation. Furthermore, demand side management can promote multiple utilization of wind power at valley period and flexible pricing mechanism for wind power is needed to implement it.

## 6. Concluding remarks

Wind power is the mainstream green energy source with massive potential. With the publication and implementation of a set of energy policies, large-scale wind power development is taking off in China. In this paper, with a supply chain perspective, we try to figure out the panorama of China's wind power industry. Key stakeholders in the supply chain and their concerns are identified to understand the challenges of the industry. Then with a brief outline of the pertinent policies, status quo and issues of the supply chain are analyzed. Three remarks are made to conclude the paper.

First, on wind turbine manufacturing, the orientation of industry policy should be independent innovation capability, instead of scale of domestic manufacturing. To foster innovation, a strict national technology standard system should be formulated to elevate the entry

threshold. A national innovation system should be formed, which is consisted of basic R&D by public research institutions and universities, public-private partnership for engineering and demonstration, and strong private innovation for marketable products protected by strict intellectual property protection. The government should keep a close eye on market competition behaviors and intervene with anti-trust measures at necessary time when vicious competition is detected.

Second, on wind farm development, the orientation of the government should be balanced planning with consideration of grid integration capacity and level playground for all prospective investor. The development pattern of wind farm should also be amended. In addition to the current concentrated large-scale wind farms, medium-and-small-scale wind farms directly balanced with local demand would also be encouraged to reduce the burden of grid integration and demonstrate the feasibility of distributed generation and micro-grid. Development of smart grids will be strong support for the new patterns.

Third, on final utilization of wind power, grid companies should be properly motivated to integrate wind power into power grids. Practical technical codes for wind integration and dispatching rules friendly to wind power and other renewable energy will be a good start. Then proper allocation and recovery of the additional investment and operation costs should be settled by reform of tariff mechanism. Separation of transmission and distribution price from retail price, and pricing the transmission and

distribution service based not only on its cost but also on service quality can provide strong incentive for grid companies, while the demonstration of distributed generation and microgrid will exert pressure on grid companies to improve their service.

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## Appendix

See Table A1.

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